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SOLVING SEMICONDUCTOR PROBE CARD PROBLEMS UTILIZING TRIZ AND DATA ANALYSIS

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Abstract: *In accordance with the demand for high-quality / high-performance characteristics of semiconductor products worldwide, highly integrated new products using advanced technologies are being developed and released. In the final stage of FAB (Fabrication, semiconductor production line) in the semiconductor manufacturing process, a probe card is used to test the operation of the semiconductor.*

This paper addresses the process of analyzing problems and deriving solutions using the TRIZ and 6-Sigma methods for problems that occur when measuring highly integrated products using probe cards in the semiconductor industry.

SK Hynix, one of the world's largest semiconductor companies, has several factories in Korea and China. The solution idea, developed at one plant in Korea, is applied at other plants in China. The solution contributed not only to our company, but also to the other probe card manufacturers in the industry.

Keywords: *Semiconductor, TRIZ, 6 Sigma, Probe card.*

1. INTRODUCTION

1.1 Semiconductor Environment

In the era of the 4th Industrial Revolution, semiconductors are attracting attention as a major component for smart devices, artificial intelligence, 5G, Internet of Things (IoT), and automobiles. The importance of miniaturization of semiconductors is increasing as it is inserted in palm-sized mobile devices and also in wearable devices for the body. Looking at the customer's miniaturization requirements, the average package size change demonstrating integration is as follows: 100 mm^2 in 2010, 62 mm^2 in 2012, 38 mm^2 in 2015, 18 mm^2 in 2016, 8 mm^2 in 2017. The pad contact size of the probe has an ideal performance at 10*10 µm and has a structural characteristic that the width of the probe is continually reducing.

In reviewing the environmental changes for semiconductor equipment products, semiconductor integrated circuit technology has been developed, and memory devices are being developed into products that use faster and lower power. As a result, the complexity of the devices constituting the semiconductor device is greatly increased, and the channel of the equipment has been expanded to test many chipsets at a time as a method of improving productivity. To cope with this, the overall size of the probe card increased and the number of probes increased significantly. The total change shows the following trend: 16,000 in 2010, 32,000 in 2012, 41,000 in 2015, 66,000 in 2016, and 10,000 in 2017.

In the wafer test process, as the equipment and probe cards are changed and the equipment, products, and probe cards are combined and operated in a multi-variety production system, the problems of semiconductor micro-processing are increasing in various ways.

As it is difficult to solve various problems in one process in this project, like the contents of the innovation process and problem-solving process in Table.1., the problem is intended to be solved with a new model that combines TRIZ and 6-Sigma. The reason is that TRIZ and 6-Sigma techniques can express the core of each stage and assist to make decisions.

Table 1

Innovation Process and Problem Solving Process.

Classification	6-Sigma	TRIZ
Individual	DMAIC	ARIZ-85C, ADRIGE
Mixture	DMADV	
Fusion	TRIZ + 6-Sigma	

- 6-Sigma: D(define), M(Measure), A(Analyze), I(Improve), C(Control).
- 6-Sigma: D(define), M(Measure), A(Analyze), D(Design), V(Verify).
- TRIZ: A(Analysis), D(Define), R(Resources), I(IFR), G(Generation), E(Environment).

The optimal solution for convergence of this task is divided into problem situation, problem analysis and application of solution.

Using computer data, selection of topic for the problem can be easily made. Here, the adjustable factor optimizes the level of factors through the DOE(Design of experiments) and defines the problematic situations in detail for additional problems.

After defining the contradictions with the items defined in detail, the solution will be derived through the 40 invention principles and the principles of time/space/separation.

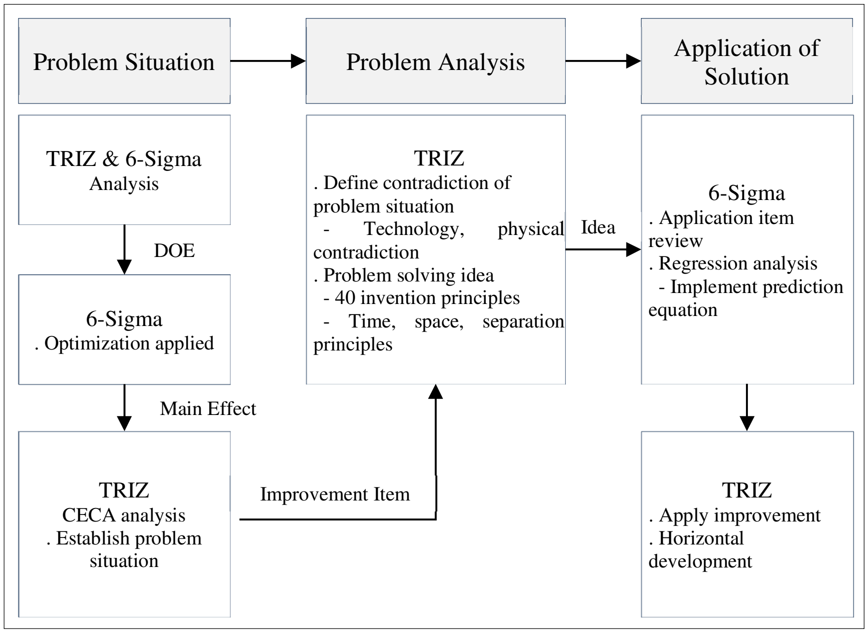


Fig. 1. Block Diagram Of Problem Solving Process.

1.2 Wafer Measurement Process

The semiconductor process order is to form and inspect the circuit of the wafer through various processes of fabrication by wearing a circular silicon wafer, and in the wafer test process, inspect the quantity of the circuit quality of the finished wafer. In the final process, the package product is inspected and through the module inspection, the product will be shipped.

The wafer test process includes wafer receipt and equipment movement, EPM (Electrical Parameter Monitoring) test, WFBI (Wafer Burn-in) test, hot & cold test, quality inspection, and shipping process.

In the test process, circuit pattern anomaly detection and voltage / current characteristic anomalies in high / low temperature environments are discriminated, and major management items in all processes include yield abnormalities, foreign substance management, probe position mismatch, and scratches.

The inspection equipment from EPM test to high and low temperature test process is composed of tester and wafer transfer equipment. The tester equipment creates and supplies the power, timing, pattern, clamp power, driver channel, and input output (IO) channel signals required for the wafer operation circuit, and the generated signals are transmitted to the tester head through the interface cable. The top of the probe card is engaged with the tester head, and the signal received from the tester equipment is transmitted. The wafer transfer equipment, which is composed of a pair, controls the high / low temperature environment, and loads the wafer to arrange it in an optimal state.

To test, each signal is finally delivered to the probe through channel expansion operations in the probe card, and the probe proceeds to contact with the probe depth at the pad of the wafer.

1.3 Probe Card

The probe card is installed in the wafer transfer equipment and is the main means for determining the normality / abnormality of the completed wafer chipset while transmitting and receiving electrical signals by contacting the probe with the wafer pad.

To explain the key terms in Partial Structure of Test Head and Configuration of Probe Card in Fig. 1., the stiffener is a support for minimizing the overall change of the probe card. The probe card latch provides the connecting function of contacting the tester head and probe card. The bridge pin minimizes the external deformation of the probe card and the probe refers to a pin that directly contacts the wafer pad and sends and receives electrical signals.

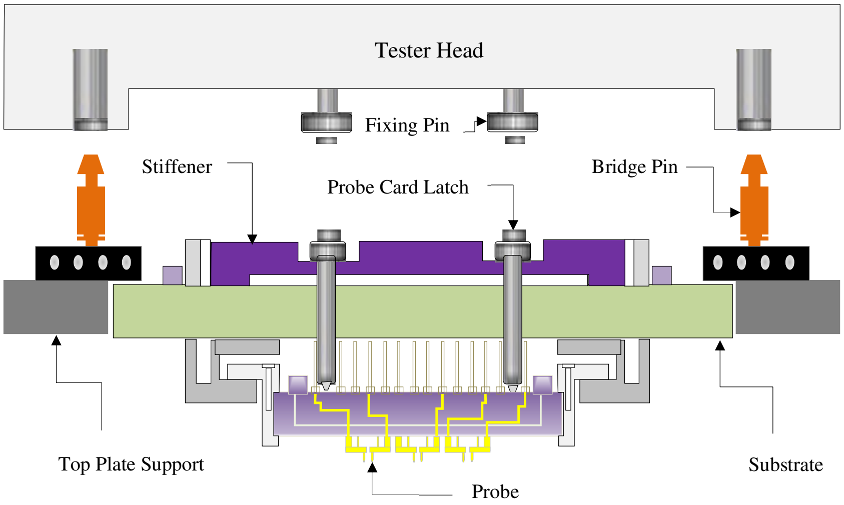


Fig. 2. Partial Structure of Test Head and Configuration of Probe Card.

2. PROBE CARD PROBLEM SOLVING

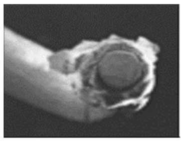
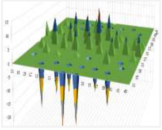
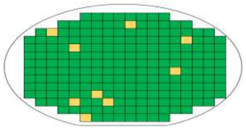
2.1 Problem Situation

The wafer transfer equipment (Prober Station) is designed to control the misalignment of the probe card and the height of the probe pressure. However, there are various problems in inspecting semiconductor chips, which are increasing in integration, with a probe card. When looking at the type of failure that causes the yield to fall in Table 2., it is classified as probe foreign matter / flatness aberration / probe pressure, and accounts for 92.9% of the total failure.

Flatness aberration and probe pressure failures frequently occurred under test conditions where the number of probes in the new equipment and probe card increased, and when the yield-degraded wafer was analyzed, it was confirmed that the probe mark was small in the central portion. The same symptoms do not occur in multiple equipment and therefore, the part where the probe card is physically connected is examined as shown in Fig. 3 and Fig. 4. The component name is explained in Fig. 2.

Table 2

Types of Failures that cause Yield Degradation

Types of Failures			Yield Degradation	
				
Probe Foreign Matter	Flatness Aberration	Probe Pressure	Legend	Conforming Product 🟩 Nonconforming Product 🟨

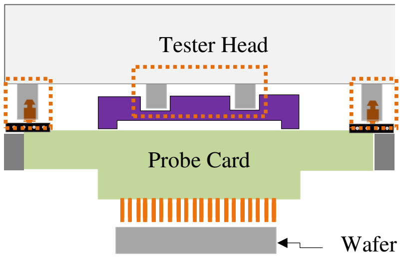


Fig. 3. Production Conditions.

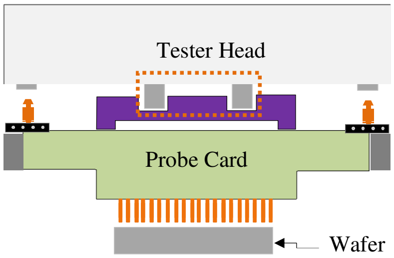


Fig. 4. Experimental Condition.

Optimization was performed from the viewpoint of operating the equipment, and through additional experiments, a method of analyzing TRIZ techniques and deriving ideas was selected.

Optimize Production Conditions. Fig. 3 as in the operation of the production conditions, the experimental conditions when connecting the probe card latch / fixing pin and the bridge pin are as follows.

- Complete factor design level 2, 1 repetition, n = 13 repetitions, Derivation of optimum conditions.
- Contact height: 0 mm, 0.20 mm, clearance height: 0.90 mm, 1.10 mm.

To summarize the experimental results, in Fig. 5 the overall satisfaction was considered at 95% or more, and the equipment was calibrated by optimizing the clearance height to 1.00 mm and the contact height to 0.0 mm.

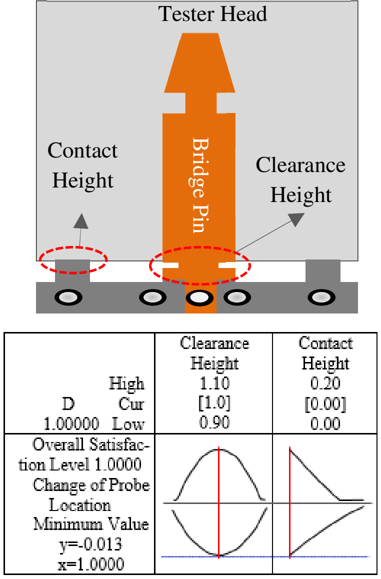


Fig. 5. Bridge Pin Diagram and Production Condition Optimization Result.

The experimental conditions for viewing the main effect data for disconnected / connected probe card latch are as follows.

- Factor 1, Types of Probe Card (1~6).
- Factor 2, Installation Method (Separation, Connection).
- Complete Factor Design n=24 2 repetitions.

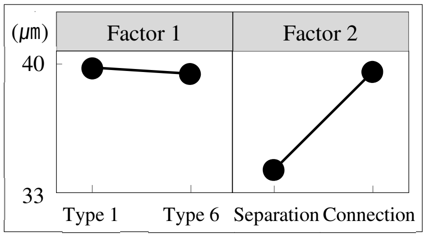


Fig. 6. Main Effect Analysis.

Through experimentation, it was evident that the amount of change in the probe when connecting the probe card latch was significant, and the measurement result, as shown in Fig. 7, showed that a difference in height between the outer portion and the center portion of the probes occurred at a maximum of 48.7 μm.

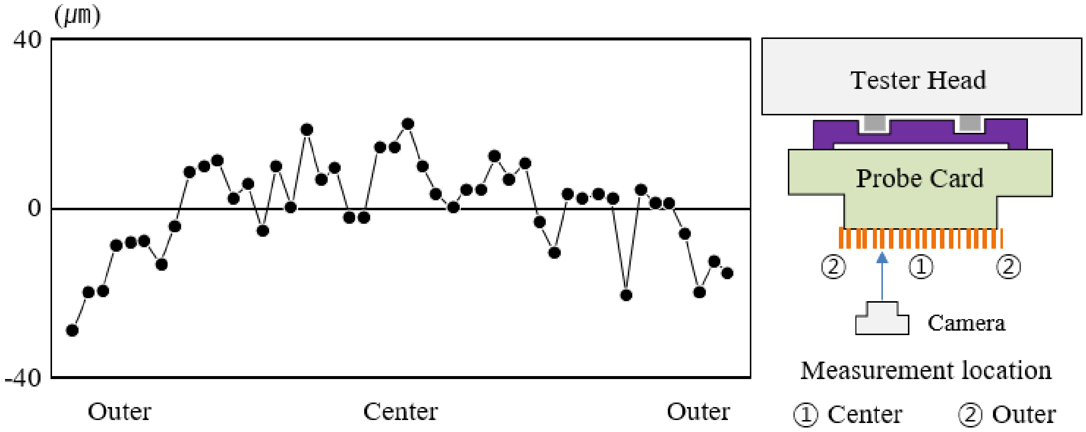


Fig. 7. Probe Height Measurement Graph when Connecting the Probe Card Latch.

Problem Situation Summary. The central concave phenomenon and the probe abnormality were confirmed in the connection state of the equipment, and in the main effect analysis result in Fig. 6, there is a significant difference in the bending phenomenon in the separation / connection mounting method. This has been confirmed to be a lot of modifications in the connection method, and the chain analysis of the cause and result was conducted and the macro level to check the probe pressure was prepared.

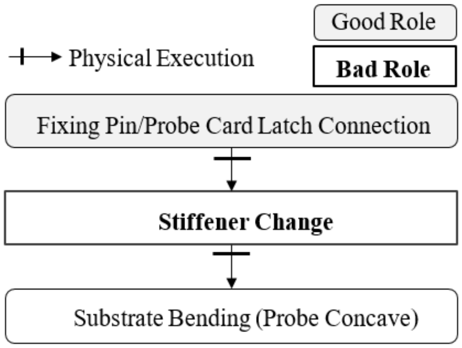


Fig. 8. Cause Result Chain Analysis.

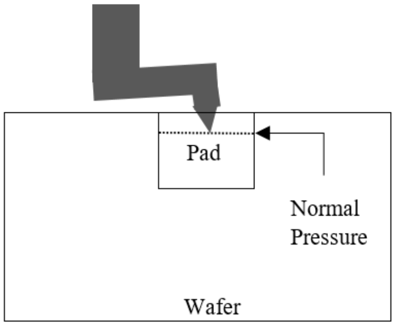


Fig. 9. Probe Pressure Macro Level.

The essence of this project is to solve the central concave phenomenon and to perform the test with the probe within the normal range of probe pressure.

Since the number of probe is continuously increasing, it is reasonable to compare the load according to the probe number. Since each probe has a force of about 1 g / mil per pin, when the probe card's total probe count is 10,000 pins, it receives a load of 31.5 kg (10,000 * 1 g * (80 μm / 25.4 μm)), and when the total probe count is 100,000 pins, it will receive a load of 315.1 kg (100,000 * 1 g / (80 μm / 25.4 μm)).

Therefore, the current probe card generates a load of about 10 times that of the previous probe card, and the probe pressure standards for each equipment / probe card are changed, so it was unable to provide the correct repulsive force to meet the test conditions.

Finally, the problem situations in the two areas are summarized as follows.

- Change of stiffener: Deformation due to connection of fixing pin and probe card latch.
- Probe pressure check: Probe pressure between probe card probe and wafer cannot be checked.

2.2 Problem Analysis

Analysis of Stiffener Change. When reviewing the chain analysis of the cause and result in Fig. 8, the problem of bending phenomenon when connecting the probe card latch was confirmed, and it was necessary to draw a detailed idea about the central concave phenomenon.

In order to draw ideas, 20 members of TRIZ collaborative research group defined the technical contradiction and as stated in Fig 10. Technical Contradiction Definition and 40 Invention Principle Selection, when the original plate of stiffener is reinforced altogether by using contradiction deepening contents, the weight will increase, and when it is weakened, the substrate will bend.

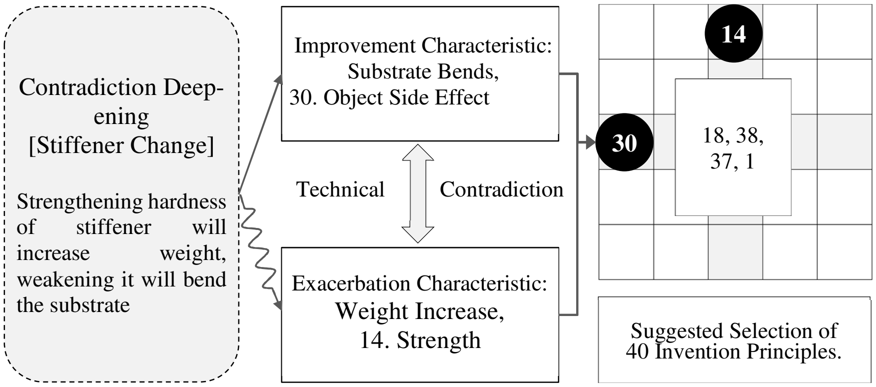


Fig. 10. Definition of Technical Contradiction and Selection of 40 Invention Principles.

The reason why weight is important when installing the probe card in the equipment is that the probe card weight had to be used within a certain range in accordance with the pressure limit of the cylinder and the protection law of the field operator.

As a result of applying the contradiction solving matrix by defining the improvement characteristics (substrate bending, “30. object side effects”) and exacerbation characteristics (weight increase, “14. strength”) when assigning parameters with defined contents of technical contradiction, the recommended 40 invention principle was extracted as “18.38.37.1”. In summary, it is the same as the definition of technical contradiction and selection of 40 invention principles in Fig. 10.

- 18 (Mechanical vibration).
- 38 (Attribute property conversion): Strengthen the center design and weight of the probe card stiffener.
- 37 (Thermal expansion): Change the probe card stiffener material without thermal expansion.
- 1 (Split subdivision): Change the shape and height of the probe card latch.

The research members schematized into economic (investment amount), technicality (resource), and productivity (production) items, and selected the most chosen probe card reinforcement central design and weight reinforcement.

Improved Probe Pressure Measurement. Looking at Fig. 12, the measurement method must proceed in a sequential process, and the probe pressure must be kept pushed back while the probe is under pressure, and the probe pressure must be maintained when the probe pressure is less than before. In other words, the probe pressure should be high and low to measure.

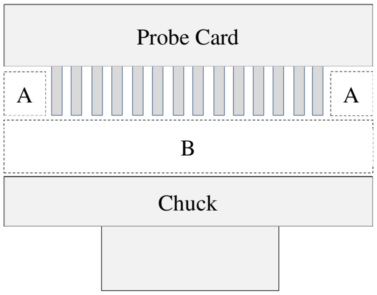


Fig. 11. Separation Principle Diagram Separation Principle Diagram.

Looking at the separation principle diagram in Fig. 11 the idea of space separation is derived from the A area to the installation space, and time separation is derived from the B area to measurement area.

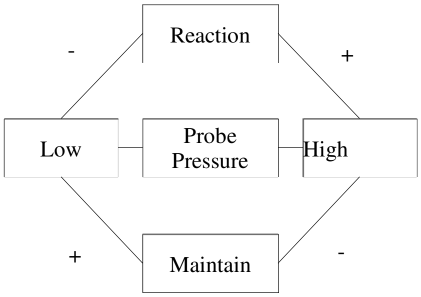
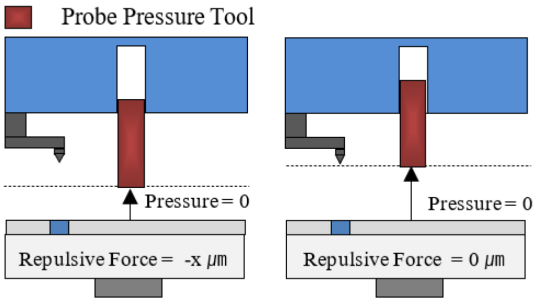


Fig. 12. Probe Pressure Contradiction Definition.



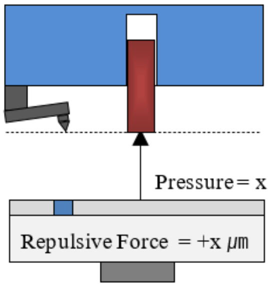


Fig. 13. Probe Pressure Tool Idea.

2.2 Application of Solution

Stiffener Central Design and Weight Change. Just like the before and after the improvement in Fig. 14., a design to optimize the design and weight was simulated, and a reinforcement plate to which the improvement design and weight change was applied was manufactured and applied.

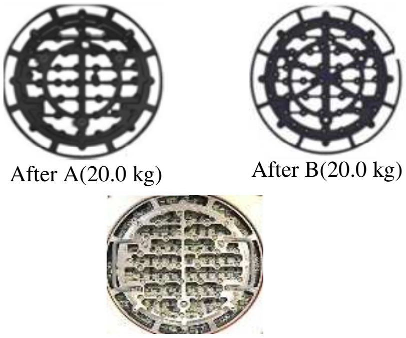
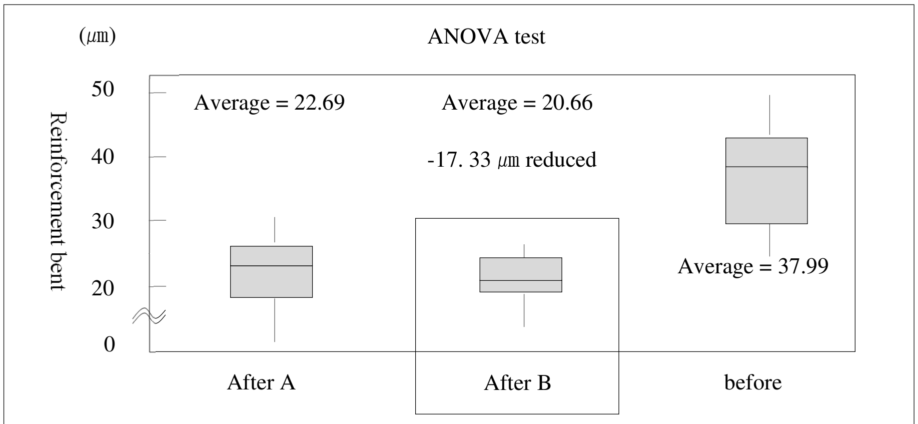

After A(20.0 kg)
After B(20.0 kg)
Before (18.0 kg)

Fig. 14. Before and After Applying the Improvement.

The total weight is one of the constraints of the line operation. It was evaluated up to 20 kg as it should be manufactured for 20kg or less. Looking at the result with the application of 20kg, the optimal effect was shown in improvement B. And as the p value of ANOVA test is less than 0.05, it can be said that the improvement was 17.33 ㎛ which is from 37.99 ㎛ before improvement to 20.66 ㎛ after improvement.



Source	DF	SS	MS	F	P
Treatments	2	2154.7	1077.3	30.97	0.000
Error	33	1148.0	34.8		
C. Total	35	3302.7			

Fig. 15. ANOVA test results according to the type of reinforcement improvement.

Installation of Probe Pressure Measurement Tool. A tool was produced to measure the probe card probe pressure, and this paper cannot show practically applied images.

A method of measuring the probe pressure tool after pushing up the repulsive force of the prober station equipment by -50 μm was adopted, and the experiment was conducted by acquiring the probe pressure data for each step while observing the probe pressure until the abnormal detection point in a certain range((-100, -50, 0, 50, 100, 150, 200, 250, 300, 350, 400) ㎛).

Table 3

Measurement Result of Application of Probe Pressure Tool.

Repulsive Force(㎛) Probe Count	Regression Formula	R^2	Regression Model	Linear Model	Residual Analysis
Hundred Thousand ~	26.27 * (0.xx*Repulsive Height)	91.0 %	Satisfactory	Satisfactory	Satisfactory
Fifty Thousand ~	14.09 * (0.xx* Repulsive Height)	95.2 %	Satisfactory	Satisfactory	Satisfactory
Ten Thousand ~	25.10 * (0.xx* Repulsive Height)	80.0 %	Satisfactory	Satisfactory	Satisfactory

Table 3. When reviewing the analysis results of the probe pressure tool applied measurement test results in Table 3, when measuring the number of probes corresponding to 10,000~ pins / 50,000 pins~ / 100,000~ pins, it was concluded that the coefficients of determination of the regression model, the probability of the regression model, the linear probability, the residual by predicted plot, residual by X plot, and residual normal quantile plot can be used with satisfaction.

Table 4

Probe Pressure Tool Regression Applied Probe Repulsive Force Use Range(XX).

Repulsive Force(㎛) Probe Count	0	50	100	150	200	250	300	350	400
Hundred Thousand ~	x	x	x	x	**XX**	**XX**	**XX**	x	x
Fifty Thousand ~	x	x	x	**XX**	**XX**	x	x	x	x
Ten Thousand ~	x	x	**XX**	**XX**	x	x	x	x	x

Table 4. The probe repulsive force was defined by the range of probe repulsive force use range that applied probe pressure tool regression and the method was pre-evaluated and applied based on new equipment ad new probe card operation procedure.

3. CONCLUSION

3.1 Effectiveness Identification

The basis for calculating the tangible effect was to apply the logic of reducing the number of failures among the logic of calculating the tangible effect of the innovation department. To calculate the reduction amount, it created a tangible effect of approximately 410 million won per 1 year: (Number of failures before improvement – Number of failures after improvement) * Failure repair time (minutes) / 60 * (Equipment price (KRW) / Depreciation period (** months) / 720 * Number of improvement facilities) * 12 months. As an intangible effect, it was possible to improve the customer reliability of other business sites and partners through sharing of improvement cases and horizontal development, and to strengthen manufacturing competitiveness as a result of innovative improvement by integrating tools.

3.2 Future plans

By integrating TRIZ, and 6-Sigma, it was possible to bring great effect of applying the optimal technology by developing the idea of finding and improving the phenomenon and by running a problem solving research group, it was possible to efficiently solve problems.

No matter how much big data there is, a good improvement with a great idea will be a meaningless improvement if there are no real factors and response variables. In the semiconductor industry, decision-making became evident by applying a converged problem-solving technique, and TRIZ plays a large role in the process of understanding and developing ideas.

3.3 Acknowledgements

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Soluționarea problemelor cardului semiconductor de probe utilizând TRIZ și analiza datelor

Rezumat: În conformitate cu cererea de caracteristici de înaltă calitate/ performanță a produselor cu semiconductor din întreaga lume sunt dezvoltate și lansate produse noi extrem de integrate, utilizând tehnologii avansate. În faza finală a FAB (Fabricare, linia de producție a semiconductorilor) în procesul de fabricație a semiconductorilor, se folosește un card de probă pentru testarea funcționării semiconductorului.

Această lucrare abordează procesul de analiză a problemelor și soluțiilor rezultate folosind metodele TRIZ și 6-Sigma pentru problemele care apar atunci când se măsoară produse extrem de integrate, folosind carduri de testare în industria semiconductorilor.

SK Hynix, una dintre cele mai mari companii de semiconductori din lume, are mai multe fabrici în Coreea și China. Ideea soluției, dezvoltată la o fabrică din Coreea, este aplicată și la alte fabrici din China. Soluția a adus o contribuție nu numai companiei noastre, ci și altor producători de carduri de probă din industrie.

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